Preliminary Results, Analysis and Overview of Part -1 of the GOLD Experiment

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ABSTRACT

The Ground/Orbiter Lasercomm Demonstration (GOLD) is an optical communications demonstration between the Japanese Engineering Test Satellite (ETS-VI) and an optical ground transmitting and receiving station at the Table Mountain Facility in Wrightwood California. Laser transmissions to the satellite were performed approximately four hours every third night when the satellite was at apogee above Table Mountain. The experiment required the coordination of resources at CRL, JPL, NASDA's Tsukuba tracking station and NASA's Deep Space Network at Goldstone, CA to generate and transmit real-time commands and receive telemetry from the ETS-VI. Transmissions to the ETS-VI began in November 1995 and lasted into the middle of January 1996 when the satellite was eclipsed by the Earth's shadow for a major part of its orbit. The eclipse lasts for about two months, until the middle of March. During this period there will be limited electrical power available on board the satellite and no experiments are planned. Post-eclipse experiments are currently being negotiated. GOLD is a joint NASA-CRL (Communications Research Laboratory) experiment that is being conducted by JPL in coordination with CRL and NASDA.

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JPL

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GOLD Task Manager

CRL IS-PHOCS

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Demonstration Overview

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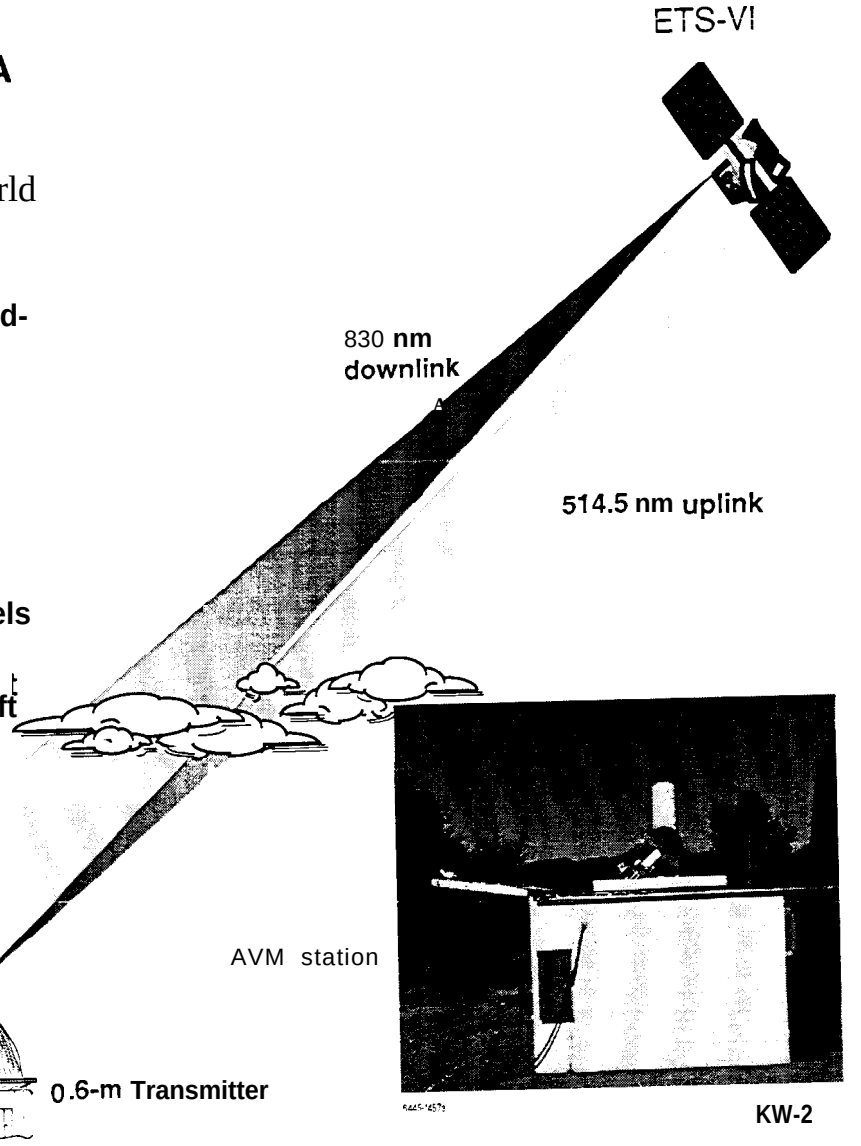
- **GOLD is a joint NASA/CRL optical communications demonstration conducted with Engineering Test Satellite (ETS-VI) by teams from JPL, CRL and NASDA**
  - **CRL extended the opportunity to NASA to perform an optical communications experiment when the satellite's orbit made it visible from ground stations around the world**
    - **GOLD Phase-1 extended from November 1995 to mid-January 1996**
    - **Satellite is in deep eclipse from mid-January to mid-March 1996**
    - **Currently assessing feasibility of Phase-1! experiments**
- **GOLD experiment objectives are to:**
  - **Obtain direct experience with optical space-to-ground communications**
  - **Validate optical communications link performance models**
  - **Characterize atmospheric effects on optical link**
  - **Demonstrate navigational orbit prediction of a spacecraft to 1 O-meter accuracy using optical 2-way ranging**
  - **Evaluate daytime performance of optical link**



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ETS-VI Ground Track

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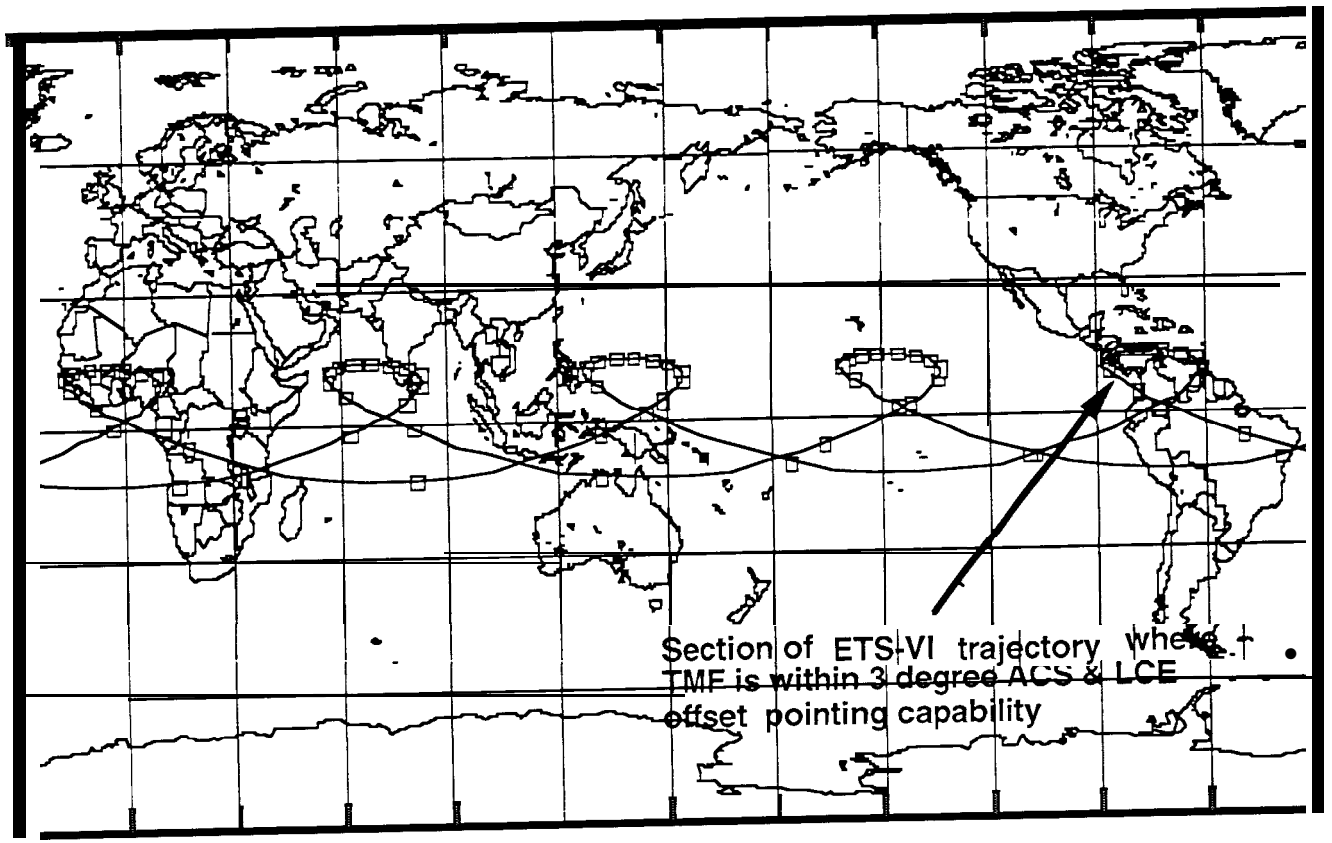
- **Laser transmission occurs as satellite goes through apogee**
  - **Uses a combination of satellite's attitude control system (ACS) and laser communication equipment (LCE) gimbal to point the transmit laser beam to TMF**
    - **Satellite is commanded via Goldstone S-band telemetry for 6-8 hours**
      - **Optical experiments last 3-5 hours**



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Operations Overview

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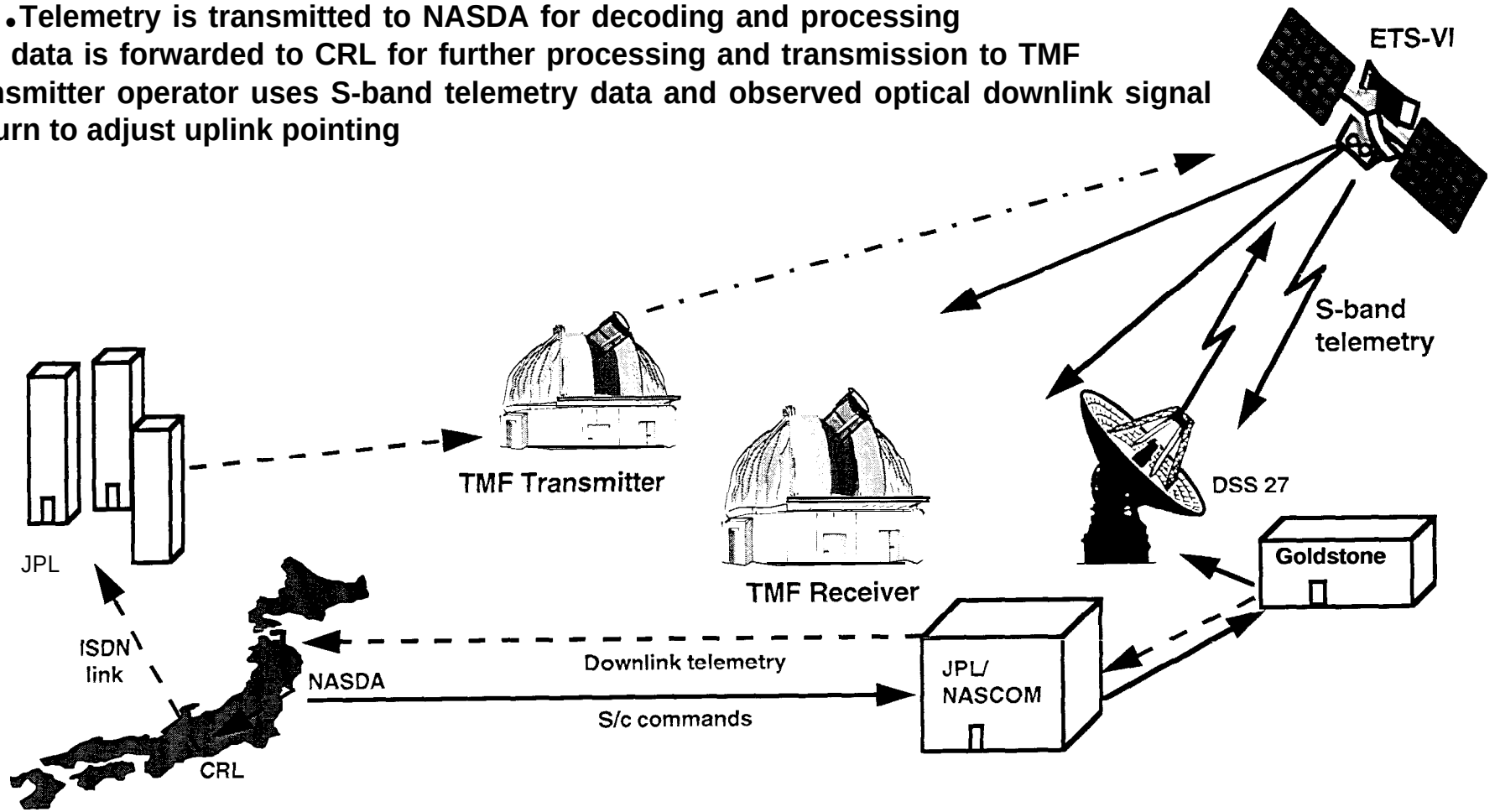
- NASDA sends commands to DSN via JPUNASCOM to control ETS-VI s/c attitude for optical link
- TMF optical transmitter initiates uplink at designated time when required s/c attitude is achieved
- Optical detectors onboard s/c detect optical uplink
- Data telemetered via S-band to 34-m DSS-27 station
  - Telemetry is transmitted to NASDA for decoding and processing
- LCE data is forwarded to CRL for further processing and transmission to TMF
- Transmitter operator uses S-band telemetry data and observed optical downlink signal return to adjust uplink pointing



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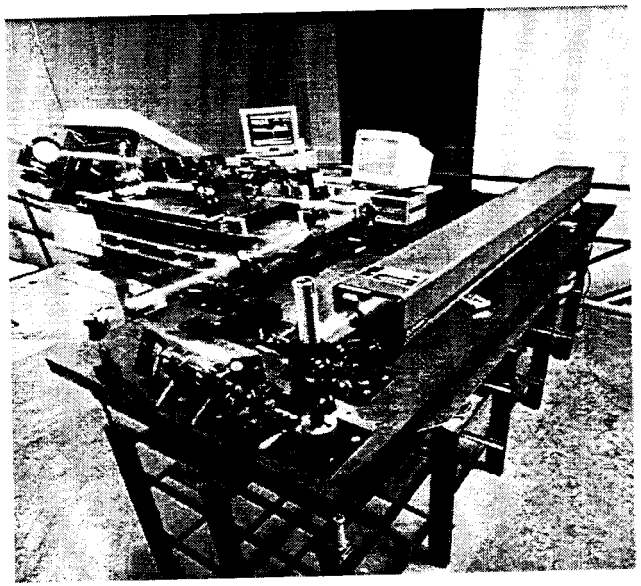
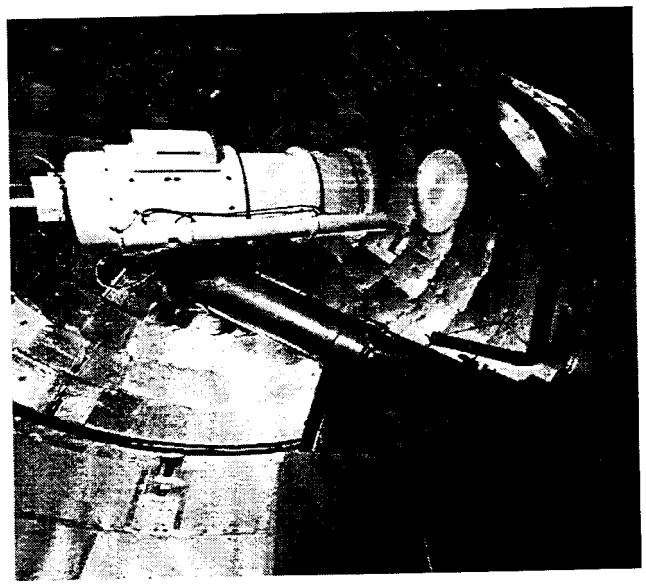
Ground Transmitter

- Transmitter is 0.6-m telescope used for Galileo Optical Experiment (GOPEX) in December 1992
  - Coude focus arrangement allows output from large, high-powered lasers to be coupled into telescope
  - Uplink laser is an Argon-ion laser that emits 15 Watts at 514.5 nm wavelength.



Argon Ion Laser in coude room of transmitter telescope



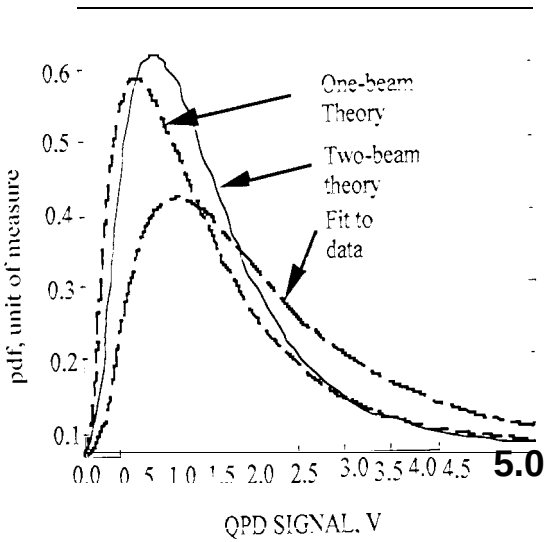
0.6-m transmitter' telescope

- Laser output is split into two equally-powered beams to reduce fluctuations in uplink signal power caused by atmospheric turbulence

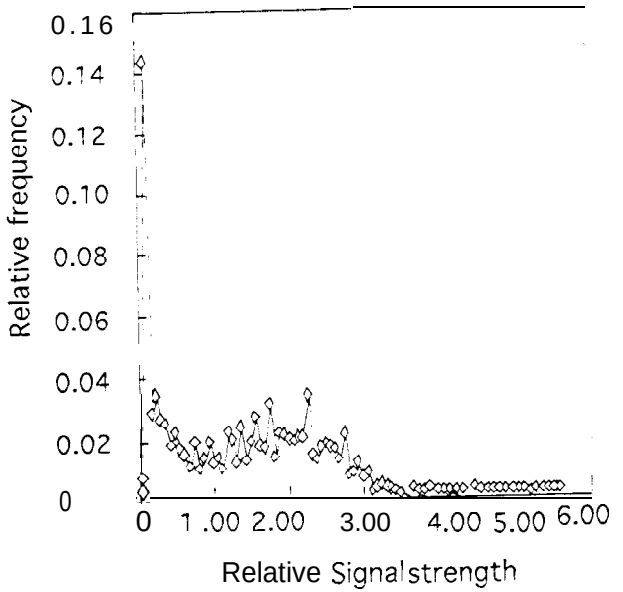
Multiple-beam Transmission

- Pathlength difference between beams was 25 cm (larger than laser's coherence length)
- Beams were propagated through telescope sub-apertures separated by greater than an atmospheric coherence cell size

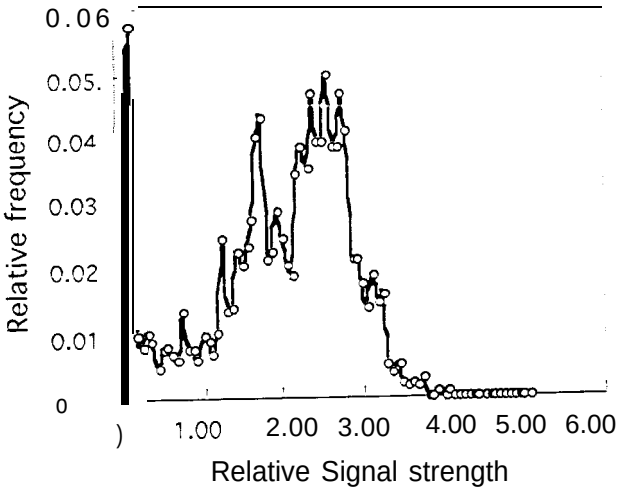
  Temporal and spatial decorrelation of beams reduces effects of scintillation
- Results are consistent with theoretical predictions and show a distinct reduction in signal fades with two-beam transmission
- Results also show that pointing errors and/or beam wander are principal cause of signal fades



Theory and fit



Single beam data



Two-beam data

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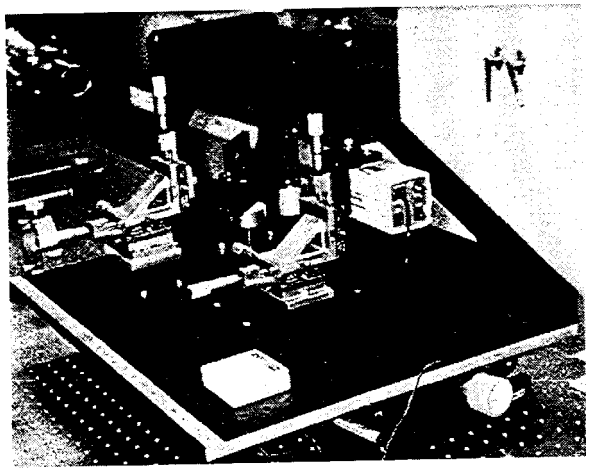
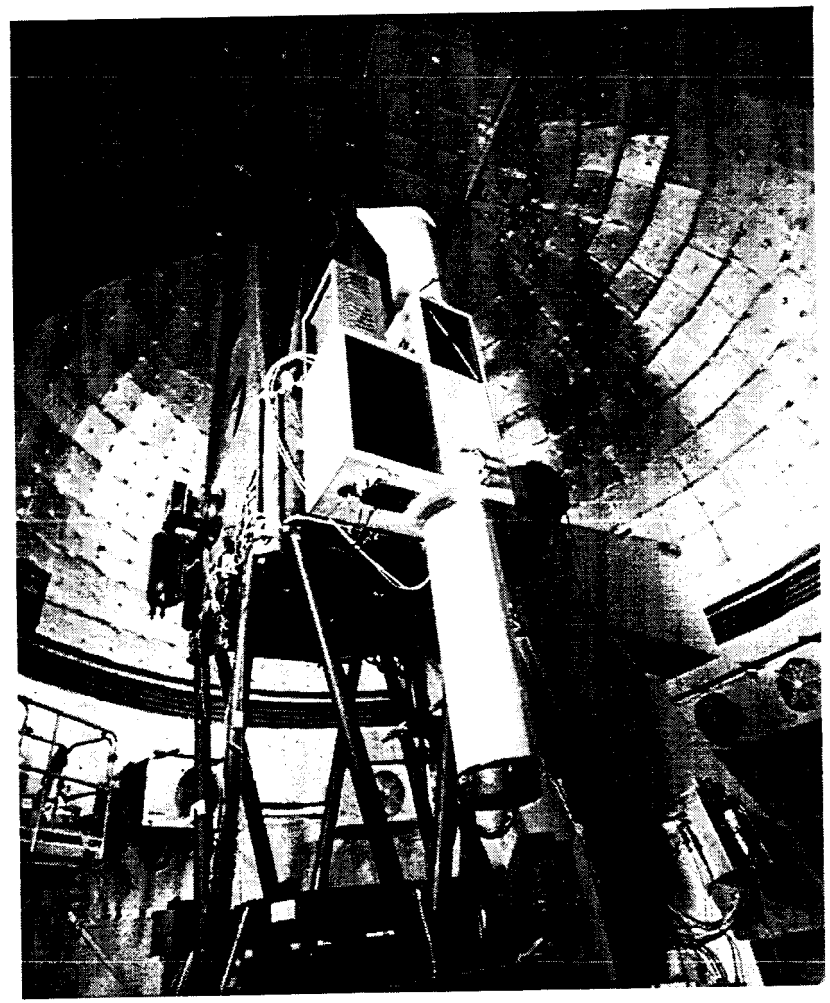
Ground Receiver

- Receiver telescope is alt-alt 1 .2-m f/29.5 bent-Cassegrain
  - Satellite acquisition, atmospheric turbulence measurements and optical signal detection assembly are located on breadboard at telescope focus
  - Assembly consists of:
    - Video-rate CCD for satellite acquisition
    - Slow-scan CCD for atmospheric turbulence measurements
    - Avalanche photodiode communications detector



Optical Receiver assembly is attached to flange at 1.2-m telescope Cassegrain focus



1.2-m Receiver Telescope

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Optical Carrier Data Stream

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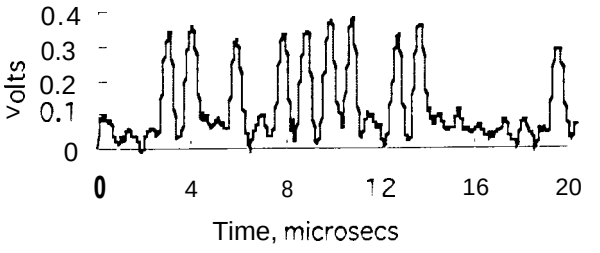
- More than 10 Gbytes of LCE down linked data were recorded over 13 experiment runs; data included satellite telemetry, PN downlink and frequency regenerated data streams

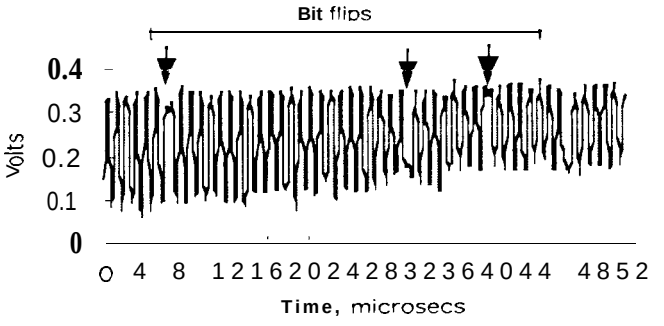
- Regeneration of uplink modulation by LCE
  - 1 MHz square wave pulse train was detected by LCE; signal was regenerated and retransmitted to ground station

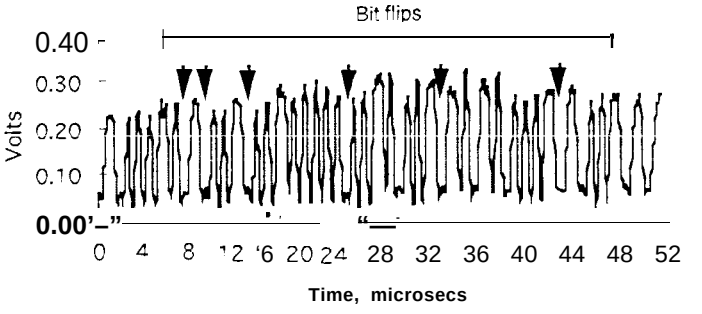
- Downlinked telemetry on LCE status
  - Blocks of the recorded telemetry data stream are being decoded
    - Results show high-data rate measurements made by LCE detectors, also includes uplink BER measurements made by APD

- 1.024 Mbps downlink PN data stream was used to measure BER on downlink; a similar data stream was transmitted up to the satellite for uplink BER tests
  - Downlink BERs ranged from 10-2 to 10-6
  - Uplink BERs ranged form 10-3 to 10-4

1 MHz regenerated signal detected at ground receiver







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Conclusion

- **GOLD Part -1 was very successful**
  - **– Experiment has generated a wealth of data that is still being analyzed. These include:**
    - **Up[ink and downlink BER measurements**
    - **Uplink telemetry regeneration**
    - **Recovered satellite optical downlink telemetry**
    - **One-beam and two-beam uplink comparison**
    - **Measurements of downlink intensity fluctuations, recorded on VCR**

- **GOLD Part -2 (post-eclipse) experiments are currently under consideration and will focus on:**
  - **Evaluating improvement in uplink signal stability achieved by using four uplink beams**
  - **Using the satellite's uplink signal regeneration capability to demonstrate optical ranging**
  - **Evaluating daytime acquisition and tracking techniques**